Marine and Petroleum Geology 103 (2019) 163–175

Contents lists available at ScienceDirect

Marine and Petroleum Geology

journal homepage: www.elsevier.com/locate/marpetgeo

Research paper

Oligocene to Neogene paleogeography and depositional environments of the Euxinian part of Paratethys in Crimean – Caucasian junction

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ARTICLE INFO

Keywords:
Miocene
Eastern Paratethys
Seismic interpretation
Sedimentology
Facies
Paleontology
Paleogeography
Paleoecology

ABSTRACT

Paleogeography and depositional environments in the zone of junction of the Crimea and the Greater Caucasus, as well as adjacent areas of the West Kuban Basin, the Sea of Azov and the Western Ciscaucasia are described based on the results of drilling works, seismic studies and multidisciplinary research. Paleogeographic maps are compiled for the early Oligocene, middle Miocene (Karaganian and early Sarmatian) and late Miocene (late Maeotian and early Pontian). The maps represented show gradual sediment filling of the deep West Kuban trough during the Maikopian and middle Miocene, and its gradual closure in the Kerch-Taman area. The deep-water connection of this trough with the Black Sea basin through the Sorokin trough had been closed by the mid-Sarmatian. The entire Kerch-Taman region became shallow by the end of the Maeotian. Significant sea level falls occurred at the end of the Tarkhanian and Sarmatian as well as in the middle of the Pontian. Large erosion channels from these times are traced on the geological and seismic profiles of the northern Scythian shelf.

1. Introduction

The first sufficiently detailed maps for the Euxine part of the Neogene basins of the Paratethys were compiled by B.P. Zhizhchenko and V.P. Kolesnikov (Neogen SSSR, 1940). These authors summarized previous geological and faunistic data (Andrusov, 1884, 1903; Gubkin, 1913; Arkhangel'skii et al., 1930, etc.). Later, the paleogeography of the South USSR Neogene basins was shown in the "Atlas of … Russian Platform …", "Atlas of … USSR" (Vinogradov (ed.), 1961, 1967) and in the "Atlas of … Paratethys" (Popov et al., 2004). Depositional environments and the paleogeography of this part of the basin in the Miocene were discussed by T.N. Pinchuk (2000) and Yu. V. Rostovtseva (2009a-c, 2012) based on faunistic data and sedimentary facies analysis.

2. Material and methods

The region under consideration constituted a principal part of the Alpine foldbelt, that was tectonically active during the entire Neogene. The Styrian and Attic orogenic phases dramatically changed the framework of deposition and paleogeography in the Crimean – Caucasian junction, and initiated large-scale tectonic and sedimentary-paleogeographic turnover in the Late Neogene (Popov et al., 2004). Main orogenesis in the Greater Caucasus took place in the Pliocene (Late Kimmerian), following earlier compressional movements during the Late Sarmatian and the Maeotian. The beginning of uplift in the Late Sarmatian changed the axial structure of the Crimean – Caucasian junction and resulted in the growth of the block fundament structures, surrounded by coastal and terrestrial sediments. The uplifting was most extensive in the Kerch - Tamanian traverse. Deposition in this region was affected by the uplift and a general regression.

The resultant paleogeographic hypothesises concerning the deposition, bathymetry, and water circulation patterns were tested by means of environmental and biogeographic data derived from planktic and benthic fossil associations and evidence of terrestrial invasions of faunas. In particular, the appearance of marine polyhaline migrants is used as an indicator for the existence of a connection with the open world ocean. However, benthos versus zoo- and phytoplankton data are often conflicting: deposits with brackish mollusks, ostracodes, and bryozoans may include polyhaline plankton associations. When interpreting these data, it is necessary to take into consideration that these benthos groups are characterized by longer life cycle and relatively

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https://doi.org/10.1016/j.marpetgeo.2019.02.019
Received 31 October 2018; Received in revised form 30 January 2019; Accepted 19 February 2019
Available online 23 February 2019

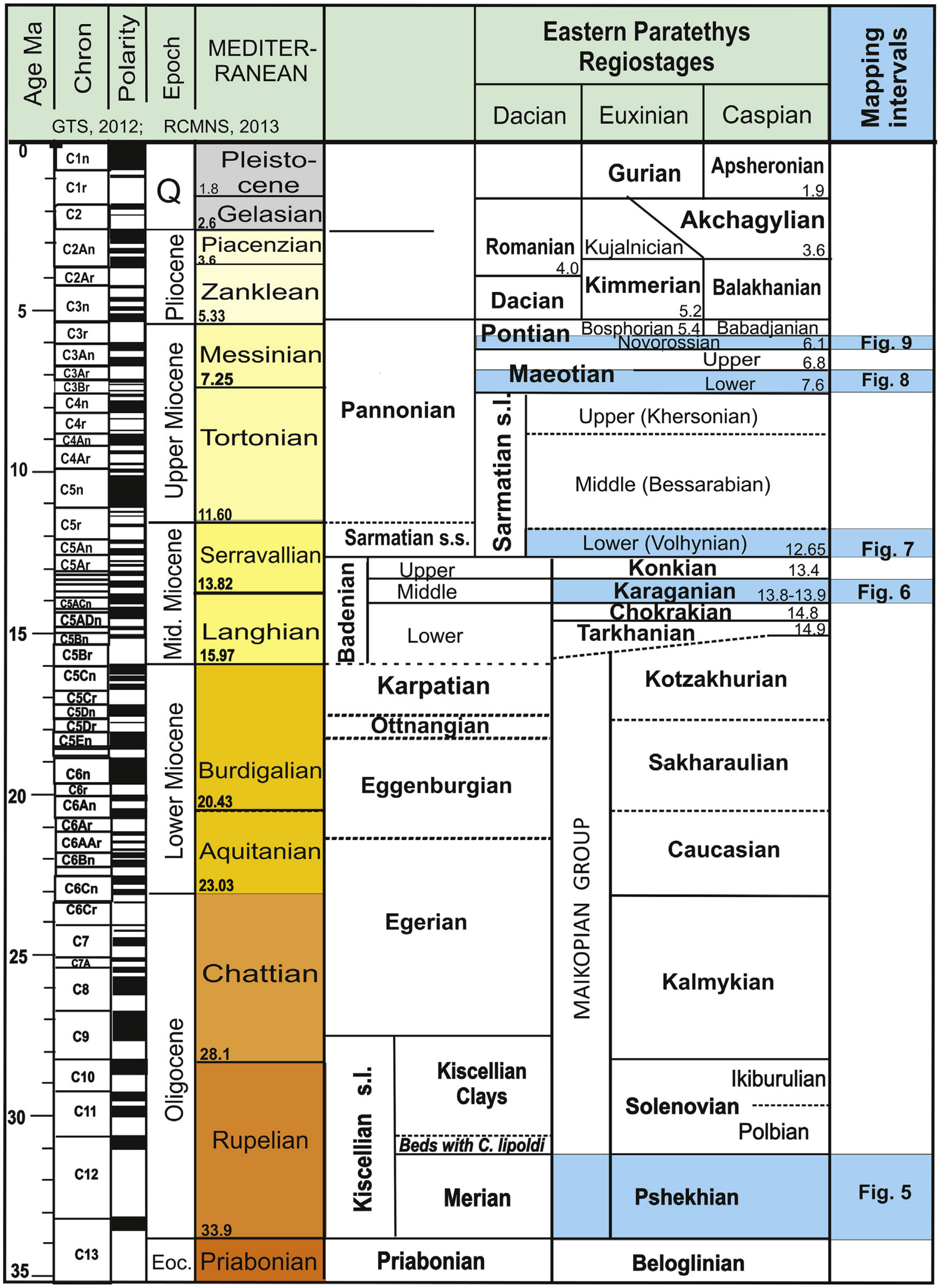

Fig. 1. Geographical position of the mapping area and the key-sections.

heavy skeleton. Therefore autochthonous benthos remains more really reflect average environments in the burial place. Allochtonous burial, when shelly material was reworked by streams or redeposited to deeper bathymetric zones as a result of slope-slide processes, can be easily recognized from taphonomic data.

In this publication we present paleogeographic maps that summarize drilling, seismic and other data from multidisciplinary research. The maps created by T.N. Pinchuk (2000) and Yu.V. Rostovtseva (2012) have been used for the Kerch and Taman peninsulas while the northern, western and eastern parts of this area (Fig. 1) have been supplemented with new materials and data published by Ismagilov et al. (2001), Barg and Stepanyak (2003), Naumenko and Korzhnev (2012), Vernigorova et al. (2012), Vernyhorova (2014). As a stratigraphic basis for interpretation of paleogeographic and facies data (Fig. 2), we used the

Fig. 2. Correlation scheme of the Eastern Paratethys with Central Paratethys and the Mediterranean and stratigraphic position of the mapping intervals.

publications of a large group of Russian paleontologists (Goncharova, 1989; Golovina et al., 2004; Radionova et al., 2012; Popov and Golovina, 2016) and the results of a paleomagnetic study (Krijgsman et al., 2010; Tari et al., 2016; Palcu et al., 2017 et al.). The adjacent areas of the Sea of Azov and Black Sea shelves are reflected in much less detail using available published geophysical, seismic profiling and drilling data.

3. Results and discussion

3.1. Maikopian basin (Oligocene – early Miocene)

The basic structural plan of the area at the junction between the Crimean Mountains and the Greater Caucasus was founded as a result of a sharp deflection in Ciscaucasia during the early Oligocene. In the Oligocene in the northern part of the Scythian plate there was an extensive basin with a wide gently sloping shelf, which occupies the central part of the modern Sea of Azov (Azov step) and the northern part of Western Ciscaucasia, named the Timashevsk bench. To the south, this shelf broke off into the West Kuban trough (Figs. 3 and 4). Based on seismic data, the development of submarine slumps and the deep-water fish fauna with luminous organs, the trough depth in the Oligocene reached about 1 km. Along the northern trough slope in the whole of the Maikopian and middle Miocene deposits, clinoform sequences could be traced corresponding to the basin slope (Fig. 3). At the base of the slope, landslide bodies were accumulated, which were later overlain by clastic sediments (Smirnov et al., 2012). Most of the terrigenous material came from the East European platform with the outflows of such rivers as the Paleo-Mius, Paleo-Donets and Paleo-Don, and to a lesser extent from the Crimean Island. Most of the terrigenous material was deposited on the Azov-Timashevsk shelf and the slope, which were intensively expanded during the Maikopian and moved from the central part of the present Sea of Azov to its southeastern part, and the northern part of the Taman area.

The restricted connection with the open seas, cooling at the Eocene-Oligocene boundary and an increase in fluvial sediment flux led to an

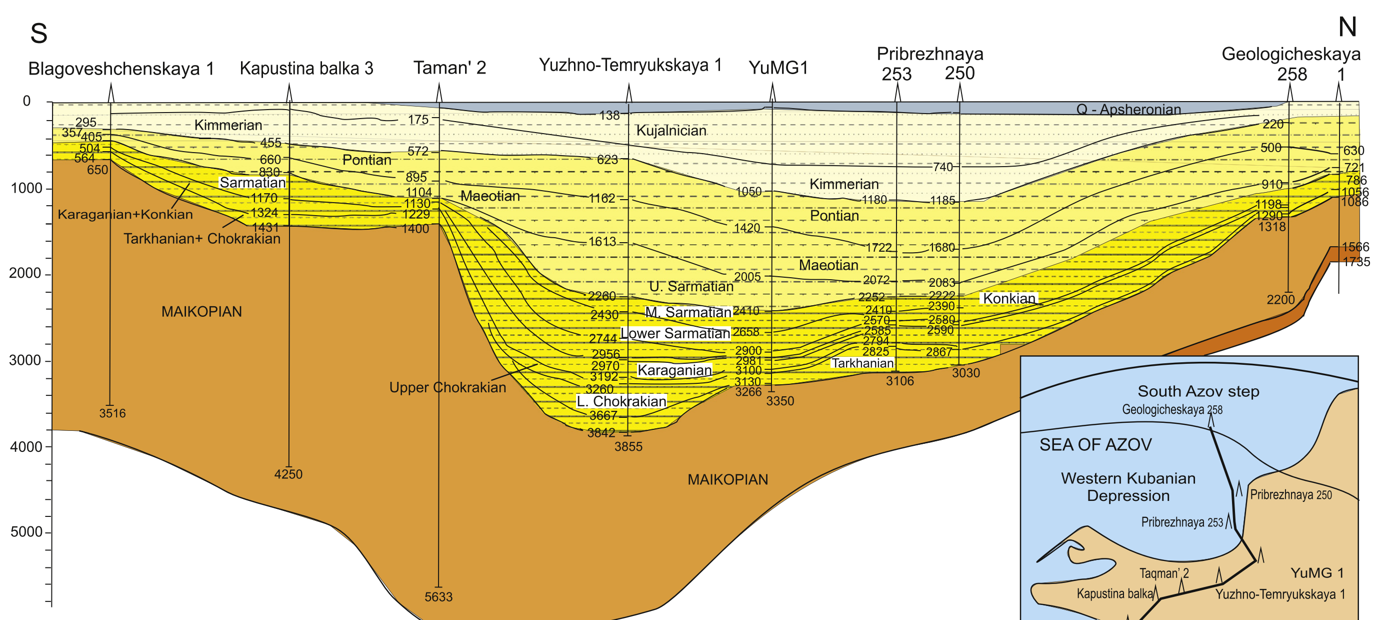

Fig. 3. Meridional profile of Taman – Sea of Azov to West-Kuban Depression.

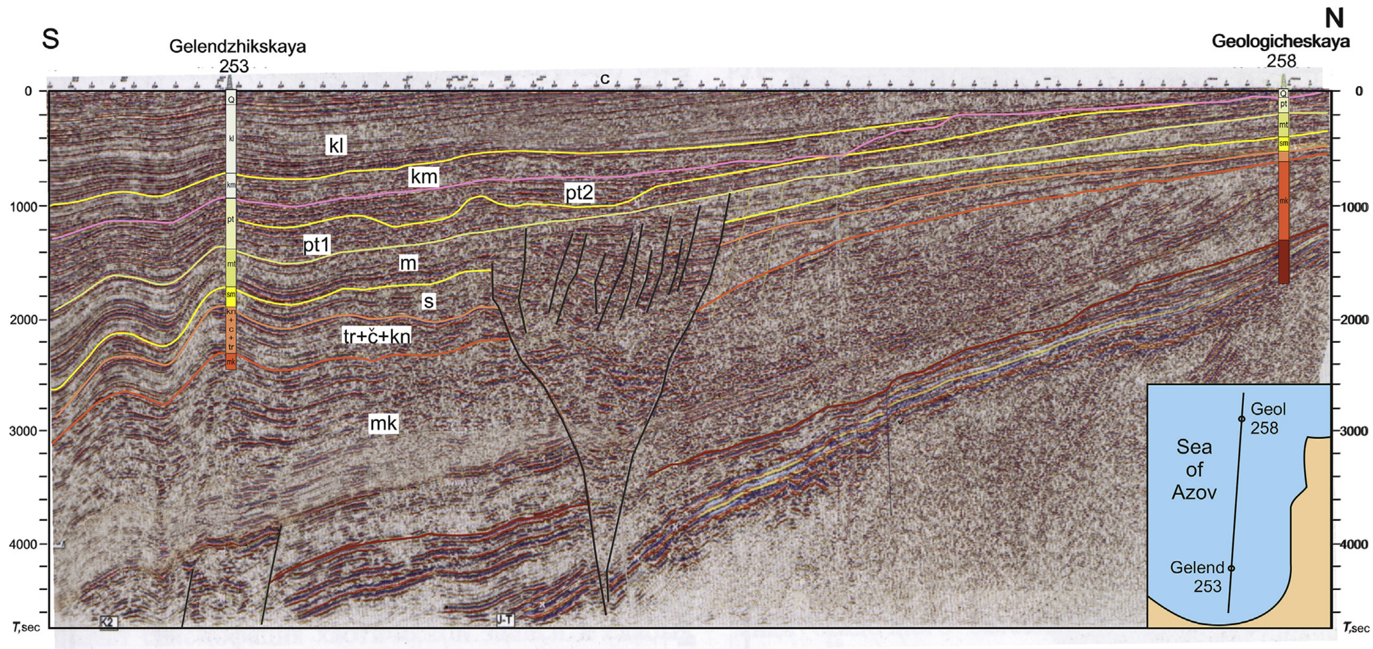

Fig. 4. Seismic profile of the northern side of the West-Kuban Depression in the southeastern part of the Sea of Azov (according to Smirnov et al., 2012, modified). It is possible to see a reduction in thickness at the top of the folds, intra-Pontian erosion and disconnection at the base of the Kimmerian.

estuary type of water circulation and anoxia. Therefore, the Maikopian deposits are extremely poor in fossils, and often from the drilling data they can only be divided into lower, middle and upper Maikopian.

3.1.1. Kerch-Taman region

Maikopian deposits in the south of Kerch and in the north of the Taman peninsulas are everywhere underline Neogene and outcrops on the surface in the cores of anticlines. Represented by clayey, deep-water and anoxic facies, the thickness of the sediments is commonly about 2–3 km. Sedimentary facies show that in the south, between the folded zones of the Crimea and the Caucasus, the West Kuban trough was open and had a connection to the Black Sea basin with an accumulation of deep-water sediments (Fig. 5), probably through the Sorokin trough. At that time, the Sorokin trough could have been much wider than it is now. In the east, the deep-water facies of the Maikopian are represented by dark non-calcareous or slightly calcareous clays, which can be traced to the Stavropol arch.

Early Maikopian shallow-water sandy facies with shells of mollusks, alluvial fans and paleo-channels are described in the western part of the Kerch Peninsula and in the Black Sea water area, where they framed the Feodosiya ledge (Naumenko and Korzhnev, 2012). Sedimentary rocks, which can probably be considered as shelf sediments (spongolites of middle Maikopian composed of sponge spicules and diatomites without terrigenous material) have been preserved up to now at the periclinal of the Caucasus in the Anapa region.

At the beginning of the Miocene the western part of West Kuban Depression was filled with clinoform sediments. In the eastern part, the depth difference remained high and reached up to 1000 m (Antipov in Popov et al., 2010). In the Azov part of the trough, a clinoform type of sedimentation continued to exist until the Konkian-Sarmatian time (Fig. 4).

3.2. Tarkhanian basin

Deep-water environments existed at the southeastern part of the Kerch and at the west of Taman regions (Fig. 6), which were far away from terrigenous material sources. In the depression areas, dark gray non-calcareous clays without fauna, but with interbeds of limestone and dolomite, continued to accumulate. The thickness of the not subdivided Tarkhanian-Chokrakian deposits was about 200 m, while in synclines it could reach up to 400–500 m. In the shallower waters of the northern and northeastern parts of Kerch and Taman with a more favorable gas regime, there was an active accumulation of gray calcareous clays with a rich fauna of foraminifera with *Globigerina tarchanensis* dominating, and miliolids, small *Saccammina*, and pteropods of the genus *Limacina* (= *Spirialis, Spiratella*) (Bogdanovich, 1965, 1974). In the Middle Tarkhanian, gas exchange was improved and marl with abundant benthic mollusks with *Lentipecten denudatus* and oyster banks with *Neopycnodonte navicularis* emerged (Tarkhan Cape, Malyi Kamyshlak, and Skelya sections).

At the beginning of the late Tarkhanian, the gas regime deteriorated again and the connection of the Eastern Paratethys with oceanic waters began to shrink (Nevesskaya et al., 1986; Goncharova, 1989). The development of euxinic conditions led to the periodic disappearance of the bottom fauna (Merklin, 1950). Based on the sedimentological and paleontological data, the bathymetric conditions for the late Tarkhanian are reconstructed as an outer shelf with depths of more than 150–200 m.

At the second half of the late Tarkhanian the depositional settings of the basin began to change: the deposits became more arenaceous, the clastics were mixed with clayey reworked ("edaphogenic") pellets indicating redeposition and transport of the sediment from shallow-to the deep-water environments, (Rostovtseva, 2012). A depth decrease by 100 m was revealed by ecological data in the Skelya Section (Merklin, 1950) The results of this regression, facies changes and condensed sedimentation, are clearly traced in seismic sections even in deep-water parts of basin, but they are usually dated as the top of the Maikopian.

3.3. Chokrakian basin

3.3.1. Early Chokrakian

Accumulation of clays similar to the underlying sediments (Fig. 6), sometimes with interbeds of calcareous sandstones (up to 20–60 m), marls and clayey coquina composed of *Limacina* continued in the basinal zone. Shallower-water depositional settings existed in the eastern Taman Peninsula at the end of the Chokrakian, as indicated by the

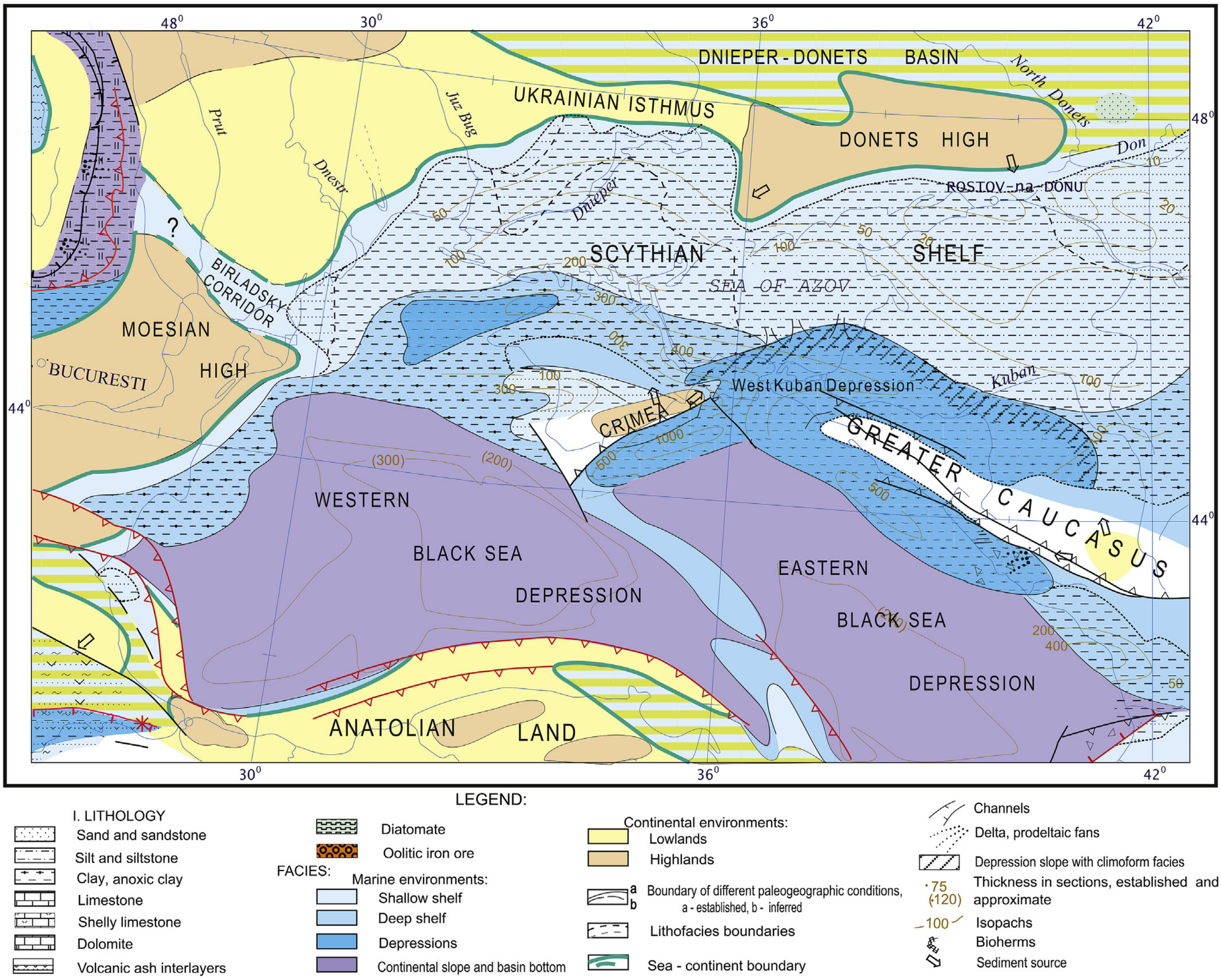

Fig. 5. Paleogeographic map of the Euxine basin in the Early Oligocene (Popov et al., 2004, modified).

presence of shelly limestone layers in the clays. Here, clays with remains of gastropods and bivalves were deposited (Shcherik, 1957).

In the early Chokrakian, the Feodosiya ledge of the Crimean Periclinal became an eroded land to which an extensive shallow area of the central parts of the Kerch area was adjoined.

Here, in the zone of wave action, shell-detritus sediments consisting of a diverse fauna of mollusks with large trochids, *Cerithium, Nassarius, Loripes* and other species were accumulated (Zhizhchenko in Neogen SSSR, 1940; Barg and Stepanyak, 2003). At the offshore-nearshore transition, bryozoan-algal build-ups were formed (Goncharova and Rostovtseva, 2009).

Along the Anapa ledge, a significant gap in the sedimentary record was observed at the base of Chokrakian. Then shallow-water sediments were deposited here. Like in the Kerch shallow-water zone, the sedimentary succession is represented by shelly-detritus, clayey-sandy and oolitic sediments with shallow fauna: *Nuculana fragilis* (Chemn.), *Ervilia praepodolica* Andrus., *Gomphomarcia taurica* (Bajar.) (Shcherik, 1957; Beluzhenko et al., 2008). Conglomerates and bryozoan-algal limestones are less common (Izmaylov, 2005).

3.3.2. Late Chokrakian

The facies distribution and the thickness of upper Chokrakian sediments indicate that a rugged relief began to form at the early/late Chokrakian transition. In the Taman region, the Karabetovo anticlinal zone began to rise with the formation of underwater uplifts. The thickness of the sediments decreased to a half or a third here. Clay sediments with extremely poor fauna with *Davidaschvilia intermedia* (Bajar.), tubules of the polychaete *Pectinaria lepidosa* alternated with calcareous-algal deposition were accumulated between the underwater uplifts (Golovina et al., 2004). Limestone facies were formed at the top of the underwater uplifts. Now these carbonate rocks are oil and natural gas reservoirs.

Due to the high fluvial sediment supply and the transportation of finer material, silting of the basin began. In the central part of the Kerch region, accumulation of shell-detritus sediments was replaced by the formation of stromatolite buildups and gypsum precipitation (Rostovtseva, 2012). In the Anapa region the formation of shell-detritus sediments continued with oolite accumulation in shallow-water zones.

3.4. Karaganian basin

In the relatively deep-water environments of the southeastern part of Kerch and in most parts of the Taman (Fig. 7), dark clays with frequent interlayers of micritic limestones or dolomites (up to 0.2 m) with infrequent *Davidaschvilia (Zhgentiana) gentilis* (Eichw.) (= *Spaniodontella gentilis*), and an impoverished foraminiferal association with *Discorbis urupensis* were formed. The formation of these carbonates as well as the shallow-water stromatolites associated with microbial

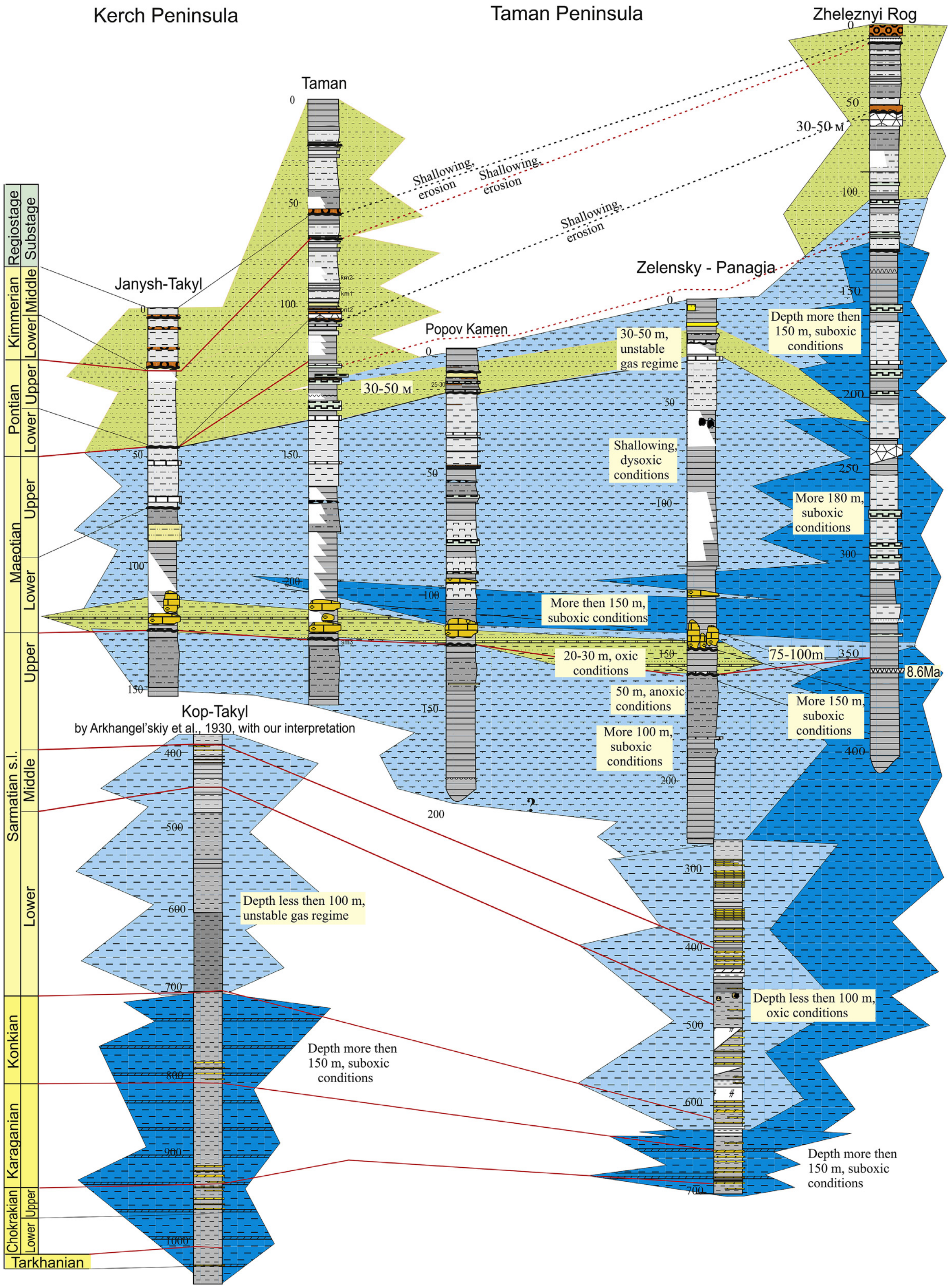

Fig. 6. Correlation of the studied Kerch-Taman sections and bathymetric interpretation of the sedimentary facies. Legend see Fig. 5.

activity occurred due to specific hydrological conditions with unstable salinity (Rostovtseva, 2012). The underwater uplifts rose slowly and had almost no effect on the depositional settings, and resulted in led to a reduced thickness only in some places.

Clays with rhythmic interlayers (0.5–1 m) of limestones, marls, dolomites and sandstones with *D. gentilis* were accumulated nearshore (Fig. 7B), suggesting transport of clastics from the uplifts of the Western Caucasus and the Crimea (Arkhangel'skii et al., 1930; Zhizhchenko in Neogen SSSR, 1940). Some rhythms include shell pavements that were formed by bottom currents. The cyclicity of sediments reflects periodical changes of wet and dry episodes compatible with Milankovitch cycles. The oxygen isotope data from calcite (shells and carbonate

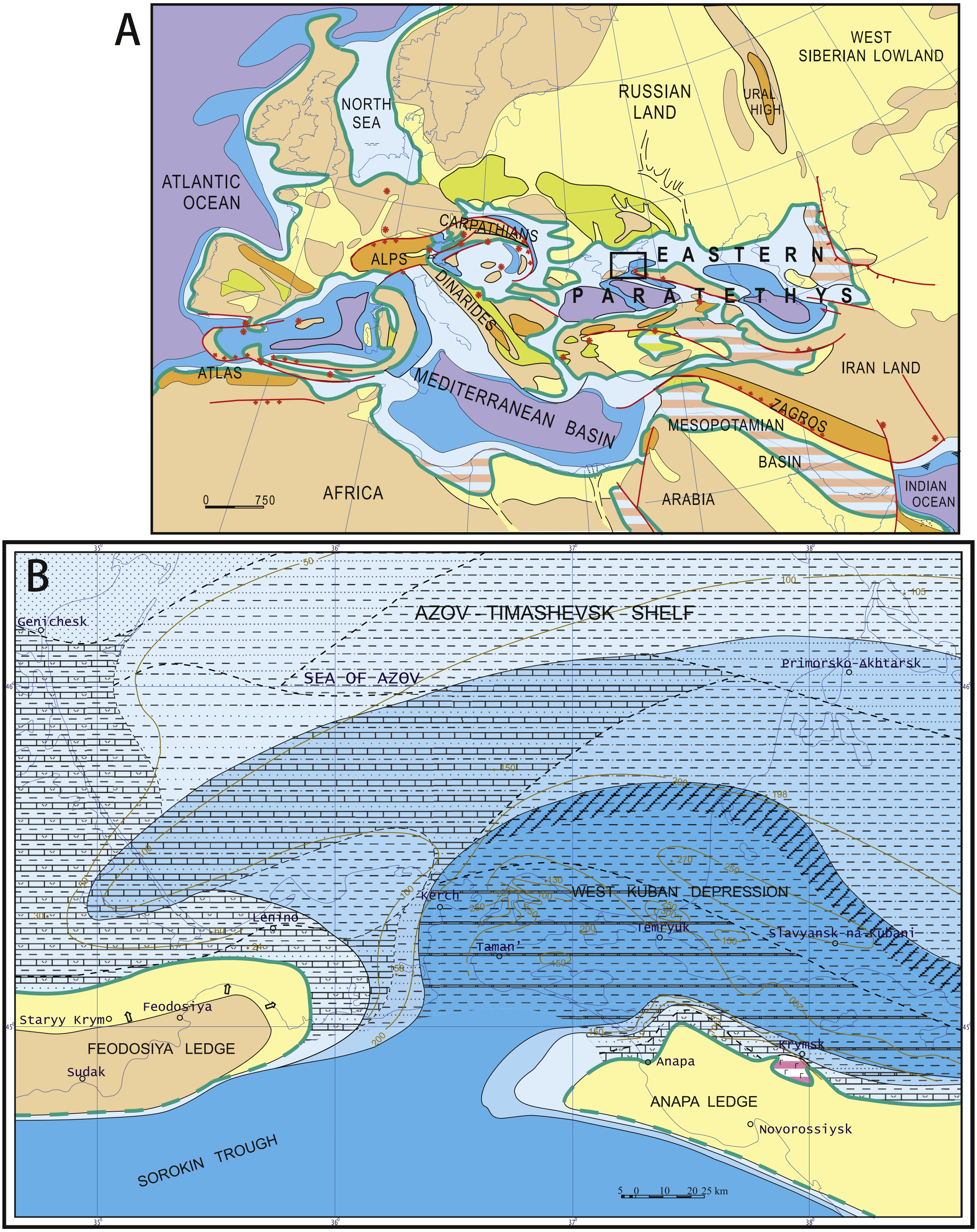

Fig. 7. Paleogeographic scheme for the Mediterranean and Paratethys realms during the Middle Miocene (according to Popov et al., 2004) and position of mapping area (A) and paleogeographic map of the Crimean –Caucasian junction in the Karaganian time (B). Legend: see Fig. 5.

rocks) of the Karaganian suggest that the clays were deposited during warm, wet periods, while accumulation of carbonates usually occurred in the cooler and dryer periods (Rostovtseva, 2012).

In shallow water settings of the Anapa region, facies of shelly limestones with *Davidaschvilia gentilis* reached a thickness of 14 m and included oolitic interlayers and limestones with *Serpula* and laminated marls (Beluzhenko et al., 2008).

3.5. Konkian basin

In Taman, the relatively deep-water conditions of the beginning Konkian were fairly similar to those of the Karaganian. The Karaganian-Konkian stage boundary here can only be defined by the appearance of the marine fauna. Over the most part of the Kerch-Taman region during the Konkian, accumulation of clays (from 10 to 15–134 m) continued in the environments of the outer shelf with depths of at least 150 m. In the undivided Karaganian-Konkian sediments three productive sandstone horizons (up to 30–35 m) can be distinguished. Periodic disturbance of the bottom water circulation resulted in oxygen deficiency and absence of benthos. Rare fragments of mollusk shells (*Abra, Ervilia)* and various foraminifers were encountered in these sediments. In the Anapa region, shell-detrital limestones continued to accumulate in shallow waters.

The broadest connection with open seas was achieved in the second half of the Konkian, when a marine polyhaline fauna was able to inhabit the basin. Progressive restriction of the Eastern Paratethys in the terminal Konkian caused a change in the open marine fauna and phytoplankton to a more euryhaline and endemic forms. Increase in river runoff led to a sharp water stratification and to the “explosion” of monospecific association of nannoplankton with *Reticulofenestra pseudoumbilica* (Golovina et al., 2004; Radionova et al., 2012), which formed a thick marker bed (0.4–0.6 m) traced along the entire southern side of the West Kuban Depression.

3.6. Sarmatian Basin

3.6.1. Early Sarmatian (Volhynian)

In the south-eastern part of the Kerch region and in the central part of the Taman clays, with beds of marls and siltstones (0.1–0.2 m) were formed in the environments of an outer shelf (Fig. 8). The water circulation was unstable, stagnation conditions periodically appeared in the depression areas. The thickness of the lower Sarmatian deposits is about 100 m. On the tops of the underwater uplifts it is reduced to 30–40 m due to erosion and transgressive overlapping by the middle Sarmatian.

In the shallow water conditions that existed in the northwestern part of the Kerch region, clays with interlayers of shelly limestones, sandy clays and sands were accumulated (Kolesnikov in Neogen SSSR, 1940). In the transition zone from shallow to deep-water conditions, bryozoan-algal build-ups were formed (Goncharova and Rostovtseva, 2009). Clays with interlayers of sands and marls, and less commonly shelly limestones 10–50 m thick were deposited in the western Azov region (Barg and Stepanyak, 2003).

In the Anapa region, thin beds of shelly limestone continued to accumulate in shallow coastal waters. To the northwest these limestones were replaced by clays with interlayers of shelly sands and marls.

3.6.2. Middle Sarmatian s.l. (Bessarabian)

At the beginning of the middle Sarmatian, mainly silty-calcareous sediments were deposited beneath the fair weather wave base, sometimes with thin interbeds of marls and siltstones. Bryozoan-algal buildups continued to develop in high-energy shallow water settings, while in the Western Crimea they were supplemented by algal-*Nubecularia* biostromes(Goncharova and Rostovtseva, 2009). During the periods of favorable gas regime, the basin was inhabited by mollusks, including *Cryptomactra pesanseris, Obsoletiformes,* and *Abra* and rich foraminiferal associations with *Dogielina sarmatica* and various *Quinqueloculina, Articulina* (Bogdanovich and Buryak, 1986). For the depressions of the shelf basin at the southeastern Kerch Peninsula (Kop-Takyl) and Taman Peninsula (Priazovskaya, Zelensky-Panagia sections) composed predominantly of clays with serpulid-microbialite buildups and shells of *Cryptomactra pesanseris*.

In the Taman area the seep carbonates with the lightest δ^{13}C value (-36.8‰) occurs due to the reconstruction of the basin and the emissions of the methane-rich fluid (Rostovtseva and Kuleshov, 2016). Limestones, clays, siltstones 40 m thick, with a rich middle Sarmatian molluskan assemblage were deposited in the western Azov area (Barg and Stepanyak, 2003). In shallow-water environments beneath the fair weather wave base, sandy-clayey sediments with a typical middle Sarmatian fauna of mollusks were accumulated at depths of not more than 50 m. In the coastal parts of the basin they were replaced by shell detritus, calcareous and sandy deposits of the wave zone (Belokrys, 1976).

Starting from the second half of the middle Sarmatian, sandy deposits became widespread, and were associated with orogeny in the Crimea and the Caucasus (Kolesnikov in Neogen SSSR, 1940). On the narrow northern shelf of the Western Caucasus, channels filled with sand-gravel material developed. In areas of low energy, small algal-*Nubecularia* buildups were formed.

To the end of the middle Sarmatian the depletion of benthic associations had been quite obvious suggesting a noticeable desalinization of the Euxine-Caspian Basin (Kolesnikov in Neogen SSSR, 1940; Iljina et al., 1976; Nevesskaya et al., 1986) and the wide spread of coprogenic calcareous deposits The freshwater diatoms (*Melosira, Pleurosigma, Pinnularia*) began to appear at the transition to the late Sarmatian (Radionova et al., 2012).

3.6.3. Late Sarmatian s.l. (Khersonian)

At the late Sarmatian the sea level became unstable, the salinity decreased up to 4–9‰ (Iljina et al., 1976). According to seismic and drilling data, in the northern shelf, the middle-upper Sarmatian boundary beds contain channels 200–250 m thick, cutting through the entire Sarmatian (Popov et al., 2010). The basin was mainly isolated; the rich middle Sarmatian fauna and microflora became extinct and very impoverished and monotonous associations of the most euryhaline groups of mollusks, foraminifers and ostracodes became widespread. Taman phytoplankton has many freshwater species, but the occasional presence of marine taxa indicates the incomplete closure of the basin (Radionova et al., 2012). Stratification of water resulted in anoxic conditions. By the late Sarmatian, the Azov part of the West Kuban depression was already filled with sediments.

Clays with freshwater organic-walled phytoplankton and diatom algae as well as with admixture of sand and silt grains related to the fluvial runoff from the East European Platform were accumulated in the depressions between the Taman anticline zones. An increase in arenaceous components of the sediments is observed at the top of the late Sarmatian, when the basin became distinctly shallow and a sharp progradation of deltaic systems occurred again (Rostovtseva, 2012).

The interbeds of vitroclastic ash are characteristic of the clay strata of the upper Sarmatian, they indicate volcanism and tectonic activity in regions adjacent to the Kerch-Taman area (Lesser Caucasus or/and Carpathians).

3.7. Maeotian basin

At the end of the Sarmatian - beginning of the Maeiotian, a set of large erosional channels well traced on seismic profiles was formed on the northern shelf, as a result of a significant drop in sea level. The pre-Maeotian sea level downfall of the Euxinian Basin is estimated by 200–300 m (Tugolesov et al., 1985); on the northern shelf, the incisions reached an amplitude of 200–250 m and cut deposits up to Maikopian (Popov et al., 2010). Later they continued to act as channels for the supply of sandy material (Fig. 9) and were filled with continental and coastal-marine sediments with a Maeotian fauna (Proshlyakov, 1999). Deep-water sections show the development of oolitic and brecciated algal limestones formed in the wave action zone (Rostovtseva, 2012). In the West Kuban depression, the boundary of the Sarmatian and the Maeotian is well traced by the log data and distribution of sandy-silty sediments (the YII horizon) with the Maeotian *Abra tellinoides* Sinz. and marine foraminifera.

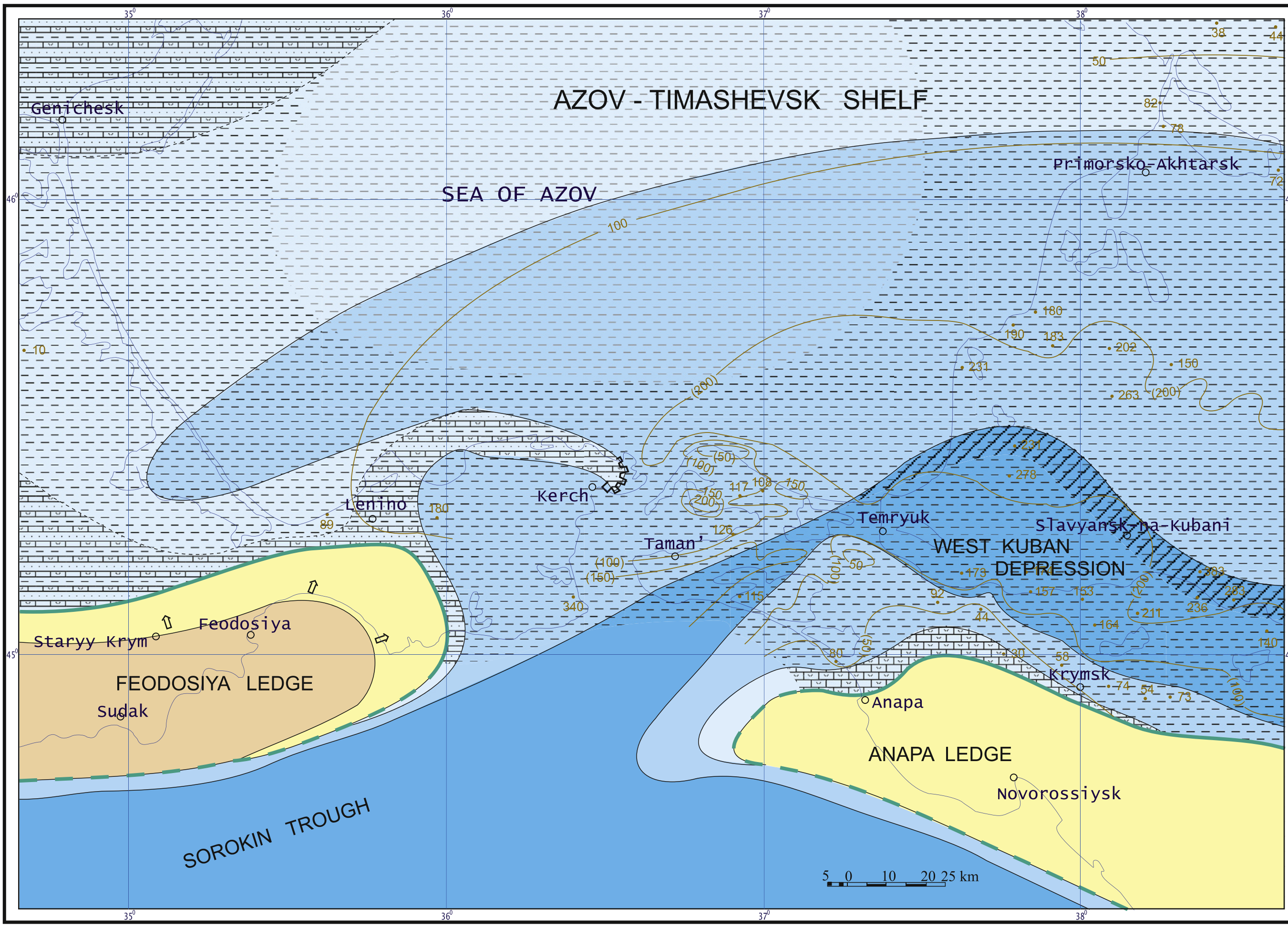

Fig. 8. Paleogeographic map of the Crimean –Caucasian junction in the early Sarmatian.

3.7.1. Early Maeotian

In the early Maeotian, the Euxino-Caspian, restricted and desalinated at the end of the Sarmatian, was reconnected with open seas as indicated by the appearance of the marine euryhaline fauna of Mediterranean origin. The development of the Maeotian transgression led to accumulation of clays and diatomaceous sediments. The axial part of the West Kuban trough and inter-dome Taman depressions with large depths were characterized by oxygen-depleted conditions due to the stable stratification of the waters.

During the early Maeotian, in the Kerch-Taman part of the basin, the bottom ruggedness and the lateral facies variability significantly increased. Subaqueous breccias (up to several tens of meters) were formed on the slopes of actively growing anticlines. The bryozoan-algal buildups (up to 10 m) began to grow in marginal parts at the tops of underwater uplifts (Figs. 5 and 8). Further transgression led to a decrease in the growth of bryozoan-algal buildups and the formation of stromatolite crusts at their tops. Later, in the early Maeotian, the bryozoan buildups began to form twice again but did not develop much.

In the western Azov area, calcareous clays with interlayers of limestone and shelly material up to 30 m thick were predominantly accumulated. Shell-detrital sediments prevailed towards the north and accumulated in high energy environments (Barg and Stepanyak, 2003). On the Azov-Timashevsk shelf, clays with interbeds of sands with shell material and oolitic limestones up to 5–6 m thick were deposited (Bogdanovich and Buryak, 1986). In the Anapa area, shelly limestones and thick bryozoan-algal buildups (up to 50 m) were formed under wave action. The sediments contained *Congeria novorossica* (Sinz.), *Abra tellinoides* (Sinz.), *Ervilia minuta* Sinz. and others; in some interlayers terrestrial mollusks were presented (Steklov, 1966; Beluzhenko et al., 2008).

3.7.2. Late Maeotian

A sharp change of sedimentation occurred at the early/late Maeotian transition following the restriction of the Eastern Paratethys and the instability of sea level. Shell-detritus calcareous and sandy sediments were accumulated in a shallow-water environment due to the wave action and the erosion of underlying sediments. In the sections of the Taman Peninsula (Zeleznyi Rog, Popov Kamen) the composition of the phytoplankton reflects the freshwater inflow (Rostovtseva and Kozyrenko, 2006; Radionova and Filippova's data in Popov, Golovina (eds.), 2016).

A thick horizon of fine-grained, delta front sandstones in the northeastern regions of the Taman indicates the progradation of the Paleo-Don and/or Paleo-Donets deltaic systems. The next horizon of sandstones in this area is revealed in the upper part of Maeotian succession (20–40 m below the top). On the broad northern shelf, shelly and sandy sediments were formed in the zone of wave action, further from a shoreline, sandy clay facies dominated (Barg and Stepanyak, 2003).

Later, due to stabilization of sedimentary environments in the Taman and the southeastern part of the Kerch areas, the mostly clay sediments began to accumulate. The relatively quiet water conditions prevailed. The intercalation of calcareous and diatomaceous clays with diatomite is largely controlled by the periodicity of seawater inflows in the freshened Euxine-Caspian Basin. The presence of calcareous nannoplankton and marine diatoms as well as sporadic appearance of

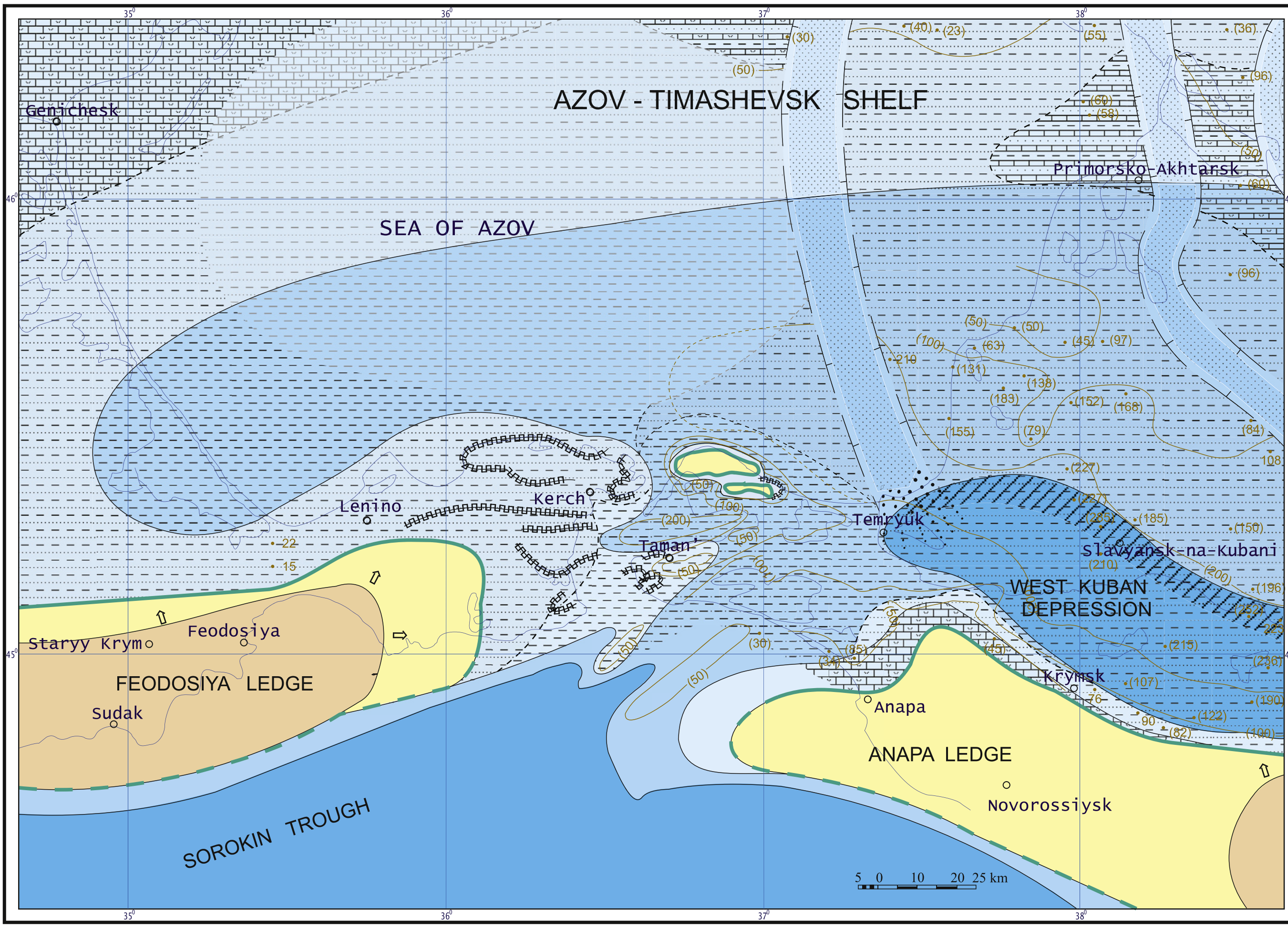

Fig. 9. Paleogeographic map of the Crimean –Caucasian junction in the early Maeotian.

marine species in the benthos (*Mactra superstes*) indicate the continued periodic inflows of marine waters and introducing of ocean phytoplankton into the basin (Radionova et al., 2012). The presence of ash interlayers indicates the activity of terrestrial dacite and rhyodacite volcanism in the neighboring regions during the late Maeotian (Rostovtseva and Parfenova, 2006).

3.8. Pontian Basin

Based on the studies of phytoplankton, the Euxinian basin at the beginning Pontian remained connected with the open sea basins, and marine water continued to flow into it with marine species of nannoplankton and diatoms (Radionova et al., 2012). However, it did not affect the composition of the benthos, which changed from a very depleted at the end of Maeotian to a more diverse brackish-water endemic in the Pontian, with only one species of marine origin - *Parvivenus vidhalmi*. It is assumed that the endemic fauna migrated to the Pontian Basin from a semi-enclosed Aegean Basin with a rich endemic fauna with *Parvivenus vidhalmi, Paradacna abichi, Pseudocatillus pseudocatillus* and others at the end of the early Messinian (Popov and Nevesskaya, 2000).

3.8.1. Early Pontian

From the beginning of the Pontian, almost the entire Kerch and Taman regions became shallow-water shelf zone with rugged bottom relief formed owing to the development of underwater anticlinal uplifts (Fig. 10). The relatively deep-water conditions (depths of about 500 m by seismic data - Antipov in Popov et al., 2010) were preserved only at the eastern axial part of the West Kuban depression.

In the south-eastern part of the Kerch area and most of the Taman area the clays were deposited in shallow-water environments (but beneath the fair weather wave base level) with high bioproductivity of diatoms, less often of calcareous nannoplankton. Among diatoms the euryhaline planktonic species *Actinocyclus octonarius* dominated, and the calcareous interlayers were composed of calcareous nannoplankton of the monodominant association with *Braarudosphaera bigelowii* (Radionova et al., 2012). According to E.P. Radionova and L.A. Golovina, such sediments are indicators of the ancient hydrological front zone formed along the periphery of fluvial inputs entering the basin. The diatom sedimentation and the invasion of marine phytoplankton stopped in the middle of the early Pontian.

At the northern shelf and in the southeastern part of the Azov step the sediments with a thickness from 2 to 50 m represented by detrital shelly limestones, less often silty clays with shells of mollusks were deposited in shallow-water zone with wave activity (Barg and Stepanyak, 2003). Towards the deeper-water zone of the basin, these sediments were replaced by calcareous clays with interlayers of sand and detrital material with *Paradacna abichi.* Sediment thickness at the northern shelf changed from 50 to 70 m and reached 300 m in the southeastern part of the Azov step and in the West Kuban depression (Fig. 3). In the Anapa region thick oolitic-detrital calcareous and sandy sediments (50–100 m) were deposited at the narrow zone of coastal shallow water.

A strong regression occurred in the middle of the Pontian. Drilling and seismic data indicate the formation of new incisions on the Scythian shelf above the Timashevsk bench (up to 400 m) and in the

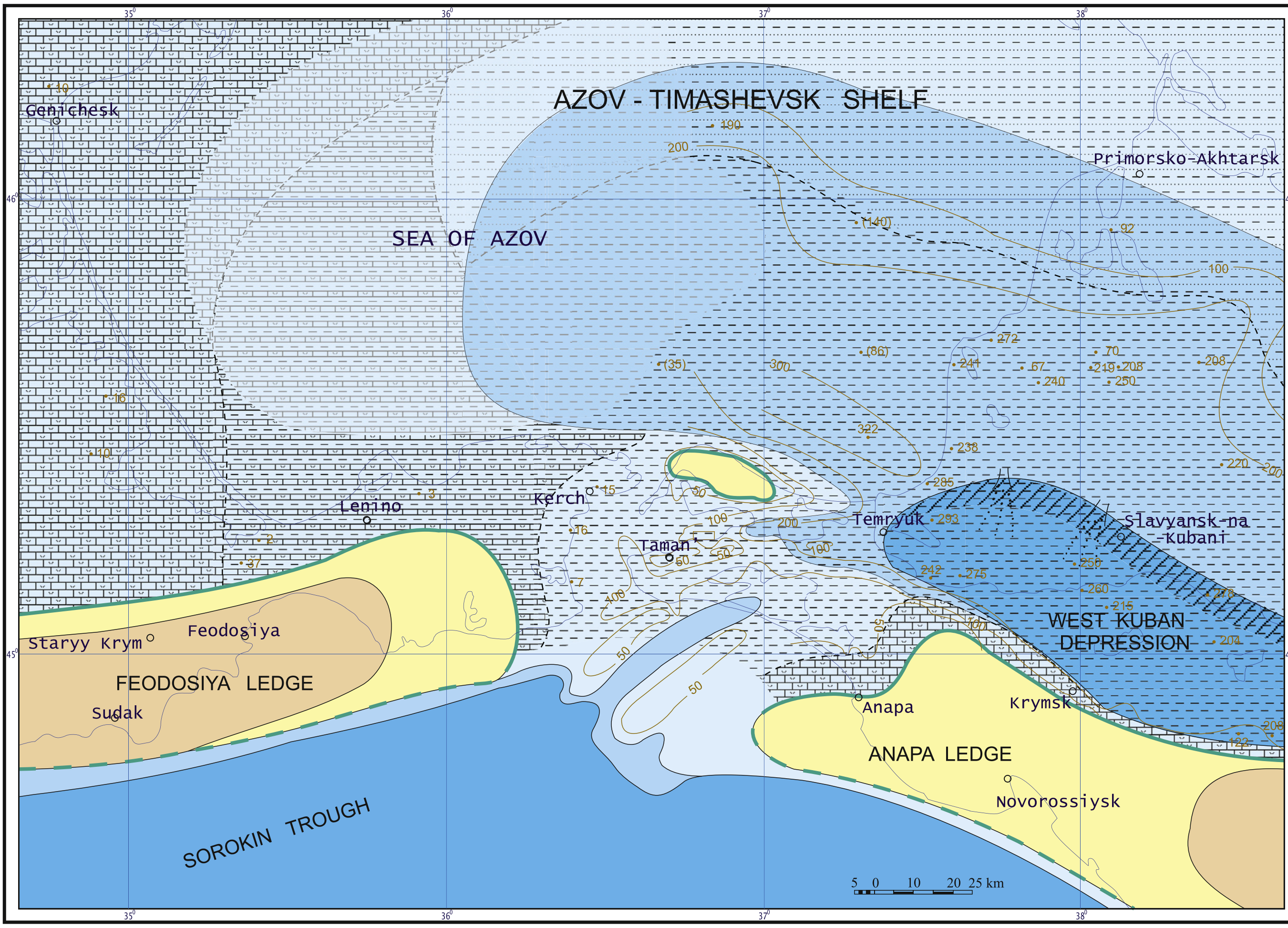

Fig. 10. Paleogeographic map of the Crimean –Caucasian junction in the early Pontian.

Black Sea (up to 300 m) (Tugolesov et al., 1985; Gillet et al., 2003). The gap in the sedimentary succession, appearance of terrestrial gastropods, and accumulation of clays with high kaolinite contents are recorded in the Zheleznyi Rog section (Popov, Golovina (eds.), 2016; Rostovtseva and Rybkina, 2017). In the southeastern part of the Kerch Peninsula (Tobechik lake) the horizons of paleosols were observed. However, the water level drop was short-term and did not lead to the formation of a deep paleo-incisions on the land. The Paleo-Don channel for Pontian time is estimated from −20 to −40 m (Zastrozhnov's data in Popov et al., 2010). After this event the Black Sea depression forever lost its free two-way connection with the Caspian Sea.

3.8.2. Late Pontian

The late Pontian sediments of the Euxinian Basin have a limited distribution. These sediments are found on the depression zones also as on the northern shelf based on drilling data. In Taman at the beginning of the late Pontian, the silty clays and clay breccias were formed in irregularities of bottom relief due to rapid sea level rise and redeposition of sediments (Rostovtseva, 2012). The formation of these underwater-colluvial sediments was accompanied by the accumulation of shell detritus interlayers. The sandy-shell and calcareous-detritus sediments were deposited at the top of the raised underwater anticlinal uplifts. In some places, sediments with the traces of considerable erosion and with interlayers of pebbles were accumulated.

At the second half of the late Pontian in the southeastern part of the Kerch and whole Taman area the accumulation of thin-bedded clayey sediments with an admixture of shell material, sand and silt took place within an underwater plain. These sediments represented by the interbedding of more calcareous light gray clays with less calcareous dark gray clays, are characterized by cyclic structure reflecting climatic fluctuations.

Taking into account the isotope data, the more calcareous light gray clays with shell of *Dreissena (Pontodreissena) rostriformis* Desh. characterized by more heavy oxygen isotope composition ($\delta^{18}O = -0.7‰$) were formed during colder and dryer climatic periods. The shell of *D. (P.) rostriformis* taken from the less calcareous dark gray clays is more enriched in light oxygen isotopes ($\delta^{18}O = -1.1‰$) (Rostovtseva and Kuleshov, 2016).

On the western part of the Azov region, continental environments were established. In the western and northern parts of the Kerch and in the Anapa region calcareous shell detritus sediments continued to be form in the wave action zone, sometimes with sand and pebble layers.

3.9. Pliocene basin

At the end of the late Pontian, the next major regression occurred, when the entire Northern Black Sea and the present shelf of the Azov-Black Sea basins were almost completely drained (Semenenko, 1993). Only the deepest areas of the West Kuban depression remained under water. The Azovian beds of the lower Kimmerian everywhere in the Taman and Kerch sections transgressively lie on the Pontian or the more ancient deposits.

The main part of the Euxinian Basin in the Kimmerian was located inside the water area of the modern Black Sea and Sea of Azov. The Kimmerian sediments exposed on the Kerch and Taman peninsulas are presented by shallow-water facies: clays with interlayers of ferruginous sands and oolitic iron ores, often with a lot of mollusk shells. Only in the axial part of the West-Kuban trough, where depths according to seismic profiling reached 500 m, is clinoform sedimentation with lateral extension of the slopes observed.

4. Conclusions

1. The general structural plan for the central part of the northern side of the Euxinian Basin in the Oligocene and Neogene was inherited from the previous seas of the Paleogene. Its main elements were the extensive shallow shelf of the Scythian plate, complicated by the deep West Kuban trough and the folded structures of the Crimea and the Great Caucasus (Fig. 5). Second-order structures in the late Miocene were represented by the growing southwest - northeast compression anticlinal folds (Fig. 4) at the periclinal of the Great Caucasus. The development of these structures determined the main features of paleogeography, the distribution of depths and sedimentary facies in this part of the basin.
2. At the beginning of the Oligocene, the West Kuban trough deepening considerably (up to 1 km), and was widely open to the Black Sea depressions. The shelf facies surrounded only the Feodosiya (Crimean) and Anapa (Caucasian) swells. Thermal and haline vertical stratification of in the Oligocene - early Miocene (Maikopian) sea resulted in the anoxia, which continued with varying intensities up to the middle Miocene.
3. In the middle Miocene (**Tarkhanian**), broader connections with open basins led to the inflow of sea waters and the reduction of anoxia. As a result, the entire shelf was inhabited by benthic fauna dominated by *Lentipecten denudatus* and *Neopycnodonte navicularis* and with deep-sea fish (*Vinciquerria merklini*). At the end of the Tarkhanian, a regression occurred, accompanied by a restructuring of the basin. Even in the deep-water areas, this boundary is clearly traced on seismic profiles, but it is usually dated as the top of the Maikopian.
4. In the **early Chokrakian**, the basin significantly transgressed, but the most widespread were the shallow-water facies with coarse-grained and shell-detrital material also as with the diverse fauna of mollusks and bryozoan-algal buildups.
5. During **the late Chokrakian** in the Kerch-Taman part of the basin the rise of anticlinal folds began, between which clay sediments with impoverished fauna accumulated. Limestone facies were formed at the top of these underwater uplifts. At present these limestones are petroleum and gas reservoirs.
6. In the **Karaganian** in the zone of the outer shelf dark clays with rhythmic interlayers of laminated microbial stromatolites were deposited (Fig. 7). The anticlines almost stopped growing and did not affect the distribution of sedimentary facies. Near the shore, clays with interlayers of shelly limestones and sandstones with a sharp dominance of the species *Davidaschvilia (Zhgentiana) gentilis* were accumulated.
7. At the beginning of **the Konkian**, the depositional settings remained unchanged so the Karaganian/Konkian boundary can only be traced by the appearance of marine fauna. The richest polyhaline fauna could have inhabited the basin at the second part of the Konkian. The restriction of the Eastern Paratethys connection to the ocean during the terminal Konkian led to the replacement of the rich polyhaline fauna and phytoplankton by a more euryhaline ones and explosive radiation of nannoplankton taxon *Reticulofenestra pseudoumbilica* in the zone of the hydrological front.
8. Sharp changes in ecology and stagnation in a semi-enclosed **Sarmatian Basin** led to a strong facies variability. In the transition zone (Fig. 8) from shallow to the relatively deep-water shelf in the early and early-middle Sarmatian s. l., bryozoan-algal build-ups were formed. In shallow-water conditions, sandy-clay sediments with *Cryptomactra pesanseris* and shelly limestones dominated.
9. Since the second half of **the middle Sarmatian** s. l. (Bessarabian) sand deposits have become widespread, as a result of orogeny in the Crimea and the Caucasus. Channels filled with sand-gravel material appeared on the shelf of the Western Caucasus.
10. In the beginning of the late Miocene (**late Sarmatian** - Khersonian) the basin became almost closed, with an unstable level and frequent stagnation. At the end of Khersonian - the beginning of Maeotian a set (network) of large erosion channels was formed, as a result of a significant sea level drop. The sea level fall is estimated at 200–300 m (Popov et al., 2010) and the canyons cut the sedimentary rocks (deposits) up to the Maikopian.
11. The development of the **Maeotian** transgression led to accumulation of clayey and diatomaceous sediments and the onset of oxygen-depleted conditions in submarine depressions (Fig. 9). Bryozoan-algal buildups began to grow at the top of underwater anticlinal uplifts, and subaqueous colluvial breccias were formed on their slopes.
12. The depositional settings changed with the onset of the **late Maeotian** regression (Fig. 6), due to the progressive isolation of the Eastern Paratethys and instability in sea level. Shell-detritus and sand sediments were deposited in shallow-water environments with increasing influence of wave activity.
13. At the beginning of the Pontian, almost the entire studied area was a shallow shelf (Fig. 10). The basin was inhabited by a rich endemic brackish-water fauna of Pannonian and Aegean origin. Relatively deep-water settings existed only in the axial part of the West Kuban trough.
14. There was a sharp regression in the middle of the Pontian, when a set of new channels (up to 300–400 m) were formed above the Timashevsk bench and in the Black Sea and the horizons of paleosols were accumulated on the tops of Taman anticlines. This water level drop was probably synchronous with the peak of the Messinian crisis. Since that time, the Euxinian Basin permanently lost its free two-way connection with both the Mediterranean and the Caspian Sea.

Acknowledgments

We are grateful to our Russian and Ukrainian colleagues, together with whom we conducted paleontological and stratigraphic studies on the Taman and Kerch peninsulas - Larisa Golovina, Eleonora Radionova, Natalia Filippova, Julia Vernihorova and Natalia Dikan. For determining the age of the deposits and the correlation with neighboring basins, an important role was played by paleomagnetic data obtained by Russian and Dutch paleomagnetologists: Valery Trubikhin, Olga Pilipenko, Wout Krijgsman, Dan Palcu, Christiaan van Baak, Arjen Grothe and Annic Van der Boon.

We are sincerely grateful to reviewers J.-P. Suc and L.A. Golovina for valuable comments, which made it possible to significantly improve the manuscript and the illustrations.

Field research and graphic works were supported by a grant from the Russian Foundation for Basic Research 17-05-00047, 17-05-01085, and 19-05-00743.

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